Potential use of abrasive air-propelled agricultural residues for weed control

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Summary

A potential new post-emergence physical weed control tactic is described. It entails plant abrasion and death upon assault from abrasive grits propelled by compressed air. Grit derived from granulated walnut shells was delivered by a sand blaster at 517 kPa at distances of 300–600 mm from seedlings of *Chenopodium album* in glasshouse pots. Control was influenced by size of plants at time of treatment. Seedlings at the cotyledon to 2-leaf stages of growth were mostly destroyed by a single split-second blast of grit of < 1 s duration, but were unaltered by compressed air alone. Plants at the 4- to 6-leaf growth stages required up to 10 blasts of grit to be killed. These results indicate that small weed seedlings of susceptible species might be physically controlled by abrasion from air-propelled grit derived from suitable agricultural residues.

Keywords: abrasion, *Chenopodium album*, compressed air, grit, organic agriculture, non-chemical management, post-emergence control.

Introduction

Stringent management standards that define Organic Agriculture place limitations on how growers can control weeds (Kuepper & Gegner, 2004). Despite these limitations, many tools are available for use by organic growers (Melander *et al.*, 2005; Cloutier *et al.*, 2007; Van Der Weide *et al.*, 2008). Nevertheless, weed control remains the major agronomic limitation facing organic crop production (e.g. Posner *et al.*, 2008). Consequently, new tool development continues to be important.

Nørremark *et al.* (2006) postulated the use of air-propelled abrasive grit to control weeds. Grits derived from agricultural residues, such as maize cobs and nut shells, are used in sand blasters, which are powered by air compressors, to strip old paints or oxidized surfaces from walls of buildings, hulls of ships, etc. Far more of these types of agricultural residues are produced than are processed for grit. Thus, new applications for these grits may enhance their value for agriculture.

If agricultural residues or other natural products can be used in sand blasters to shred and kill weed seedlings, this may represent a new option for post-emergence weed control in organic agriculture. However, sand blasters never have been tested for their efficacy in controlling weeds. Thus, the hypothesis was that mechanical simplicity and ability to use agricultural residues gives sand blasters a potential for weed management, sufficient to warrant proof-of-concept experimentation. Consequently, the objective of this glasshouse study was to document some simple characteristics of sand blasters as tools to control weed seedlings.

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Materials and methods

Plant material and growing conditions

Locally collected seeds of *Chenopodium album* L. were sown in 0.5 L pots (90 × 90 mm surface) and placed in a glasshouse set at 25/15C day night temperatures. The glasshouse was located in Morris, Minnesota, USA (45°36′N and 95°54′W). Pots were filled with 0.45 L of a 1:1:1 mixture of coarse sand, peat and loam. Seedlings were thinned to two homogeneous plants per pot and allowed to grow to various developmental stages prior to treatment with the sand blaster (described below). Vigorous growth was ensured by drenching pots daily with water and weekly with a complete fertiliser solution. Plants were exposed to natural daylengths (February–April) with mid-day light intensities from 400 to 800 $\mu E\ m^{-2}\ s^{-1}$. After treatment, pots were arranged in trays in a randomised complete block design and plants were allowed to grow for four additional days. At this time, each plant was clipped at the soil surface and immediately weighed to the nearest mg.

Sand blaster and grit description

The equipment used was a cabinet blaster from Cyclone Manufacturing. The blaster unit has the size, shape and functionality of a pistol, except that it is connected to two rubber hoses. The hose closest to the nozzle is for grit intake and draws from a grit reservoir. The second hose is for air intake and is coupled to an air compressor. Once the trigger is squeezed, compressed air passes over the top of the grit hose and through the nozzle, thereby creating a vacuum that draws grit from the reservoir through the grit hose and out of the nozzle, which was circular and 5 mm in diameter.

Grit from the shells (endocarps) of walnut (*Juglans regia* L.) fruit was used in all experiments. Most grit particles in this mesh class were 0.5–1.0 mm and passed through a 20/40 mesh sieve. Grit was angular, which may facilitate cutting and shredding of weed seedlings.

Preliminary experiments indicated that grit propelled at air pressures < 414 kPa did not kill seedlings. Thus, most experiments were performed at 517 kPa. To calculate grit delivery rates under differing air pressures, the trigger of the blaster was squeezed briefly (< 1 s) one to 10 times, with each squeeze providing an instantaneous blast of air and grit. Rapid squeezing and releasing of the trigger allowed the air compressor to maintain the desired air pressure. The expelled grit was collected in a nylon mesh bag and weighed after each treatment. Grit weight was plotted and regressed against

blast number for each of three air pressures: 414, 483 and 517 kPa (60, 70 and 75 psi, respectively).

Pattern of grit delivery was determined by measuring weights of grit deposited in lines of 10 bottles (15 mm diameter orifices) spaced at 29 mm. The nozzle of the blaster was perpendicular to the line of bottles and spaced at either 300 or 600 mm from the 5th and 6th bottles in each line. The nozzle was offset from the horizontal by 45°. The experiment was repeated four times. Data for each nozzle distance from the bottle line were normalised and plotted against distance from the line centre to reveal one-dimensional patterns of grit deposition.

Blasting C. album *plants*

Each experiment was performed twice, each was devoted to a specific stage of development, and every treatment within each experiment had four replications. Growth stages of *C. album* were as follows: (i) cotyledon to 1-leaf, 15–25 mm tall; (ii) 2-leaf, 20–25 mm tall; (iii) 4-leaf, 20–30 mm tall and (iv) 6-leaf, 50–60 mm tall. All pots contained two plants and were placed 300 mm from the tip of the nozzle, and the nozzle was positioned at 45–50° angle relative to the soil surface of the pots.

For the experiments using seedlings at the cotyledon to 1-leaf stage of growth, the plants were exposed to 0 (control), 1 or 2 blasts of grit. The control plants received two blasts of compressed air without grit to guard against confusing the effects of compressed air only compared to grit propelled by compressed air. No seedlings remained in the pots after two blasts of grit; hence this was the maximum treatment level in this experiment.

Similarly, for the 2-leaf experiments, treatments consisted of 0, 1, 2 and 3 blasts. For the 4-leaf experiments, treatments in the first trial were 0, 2 and 4 blasts, whereas treatments in the second experiment were 0, 1, 2, 3 and 4 blasts. Lastly, for 6-leaf *C. album*, treatments consisted of 0, 5 and 10 blasts. In all experiments, the control (0) plants received blasts of compressed air equal in number to the maximum number of grit blasts in each experiment.

A final experiment, also performed twice, examined the effect of 0, 1 or 2 blasts of grit when 1- to 2-leaf seedlings were placed 600 mm from the tip of the blaster. Otherwise, this experiment was identical to those described above, where the nozzle was 300 mm from seedlings.

Statistical analyses

Grit delivery rate was determined by simple linear regression of grit weight vs. number of blasts, with the

slope of a regression equation equal to the average weight of grit delivered per blast. Grit delivery pattern was obvious from graphic representations of the normalised data, but also fitted a normal distribution. Statistical functions within MicroSoft Excel were used to examine both delivery rate and pattern.

Plant responses to differing numbers of blasts were characterised via the randomised complete block option in ANOVA using STATISTIX 8 software (Analytical Software, Tallahassee, FL, USA). Theoretically, a dose–response curve fit through a log-logistic equation would be a preferable approach, as is the case with continuously varying herbicides concentrations (Streibig, 1988; Seefeldt *et al.*, 1995). However, in the current case, blasts of grit are discrete units and, for small seedlings, two or fewer blasts obliterated seedlings. Thus, log-logistic analysis was unwarranted. Lastly, all analyses of fresh weight data were examined for significant effects of the two repetitions of each experiment. In no case was a significant ($P < 0.05$) repetition effect found, thus data from both repetitions were combined and reanalysed. Treatment means within experiments were considered different only when $P < 0.05$.

Results

Delivery rates and patterns

Delivery rates of walnut shell grit at 414, 483 and 517 kPa were approximately 0.74, 1.62 and 2.30 g per blast respectively (Fig. 1). The increase in delivery rate with increased air pressure was linear (i.e. increase [g] $= 0.015 \times$ kPa $- 5.42$; $r^2 = 0.98$). In other words, for each kPa increase in air pressure, 0.015 g additional grit was discharged per blast from the blasting unit.

The pattern of grit delivery was highly focused for the nozzle used in these experiments. The pattern was wider when the nozzle was 600 mm than 300 mm from the target. Of the maximum amount of grit recorded at specific distances from the centre of the pattern, 50% or more was delivered within a 70-mm wide span at the 300 mm spacing and a 110-mm wide span at the 600 mm spacing (Fig. 2). Both patterns fit normal distributions well, with r^2 values of 0.98 for the 300 mm spacing and 0.86 for the 600 mm spacing (*F*-statistics were >227). The pattern for the 600 mm distance was displaced from centre by about 7 mm, which merely reflected a slight error in aiming the nozzle during the experiments. The two dimensional pattern of grit delivery is unknown, but is assumed to be circular to oval depending upon the nozzle angle.

Plant weights in response to abrasion by grit

Cotyledon to 1-leaf seedlings were obliterated completely by two blasts of grit (Fig. 3A). With a single blast of grit, fresh weights were reduced by 92%, which did not differ from the 100% reduction by two blasts. The small positive fresh weight values recorded for the one-blast treatment often represented the presence of tissue of dead and dehydrated seedlings.

For 2-leaf seedlings, fresh weight reduction averaged 73% with a single blast of grit. Occasional plants survived but were damaged severely. This survival appeared to be more a reflection of the poor aim of the experimenter, the narrow grit delivery pattern (Fig. 2) across the 90×90 mm surface area of the pots and the distance separating the paired seedlings across the pot, rather than resistance of the seedlings to the abrasive action of the grit. All seedlings perished uniformly with two or three blasts of grit (Fig. 3B).

With 4-leaf plants, the two experimental repetitions shared the 0, 2- and 4-blast treatments, and no statistical differences occurred between these. Fresh weights of seedlings were reduced 89% by the 2-blast treatment and 96% by the 4-blast treatment (Fig. 3C). In the second repetition of this experiment, 1- and 3-blast treatments
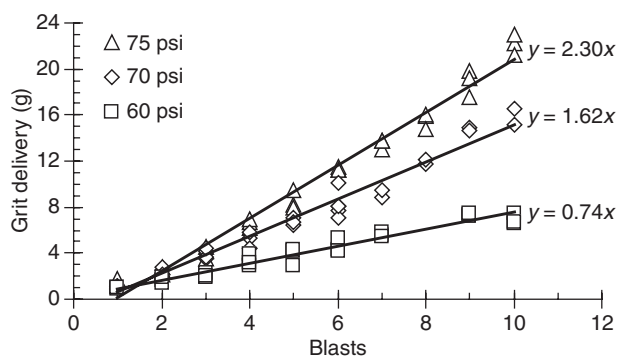
Fig. 1 Delivery rates of grit at three air pressures, 414, 483 and 517 kPa (60, 70 and 75 psi), at which average deliveries approximate 0.74, 1.62 and 2.30 g per blast respectively.
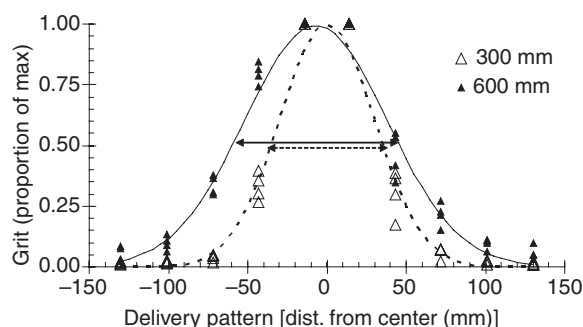
Fig. 2 Patterns of grit delivery when propelled at 517 kPa from either 300 or 600 mm distance. Arrows represent 70- and 110-mm distances within which grit delivery was at least 50% of maximum.
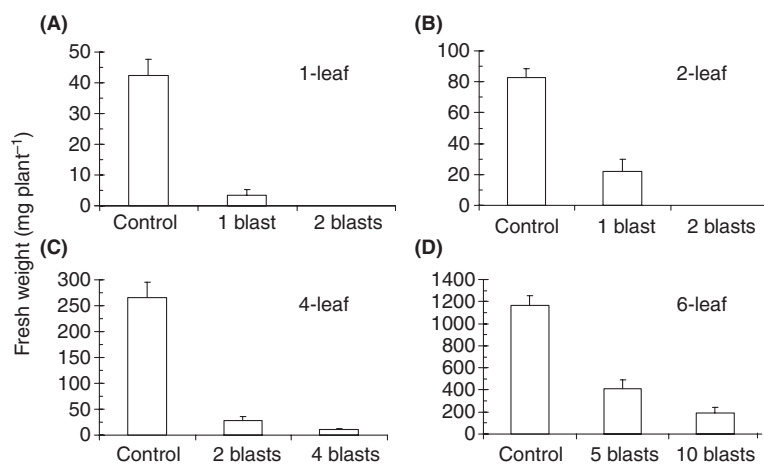
Fig. 3 Effects of blasts of abrasive grit propelled at 517 kPa air pressure on fresh weights of *Chenopodium album* seedlings 4 days after treatment. Size and development of seedlings varied with differing experiments, which were conducted at the 1-, 2-, 4- and 6-leaf (A–D) stages of growth. Bars atop each histogram represent standard errors.

were included. Resulting fresh weight reductions were 23%, 86%, 100% and 100% from the 1-, 2-, 3- and 4-blast treatments respectively. The latter three treatments did not differ from one another, but all differed from the 1-blast treatment, which itself differed from the control.

The 6-leaf seedlings were not affected greatly by one or two blasts of grit, which is why the 5-blast and 10-blast treatments were selected for experimentation. Five grit blasts reduced fresh weight of *C. album* by only 65% (Fig. 3D), which did not differ from 10 blasts that lowered fresh weights by 84%. With 10 blasts, much of the remaining weight consisted of dead and dehydrated tissue. In contrast, with five blasts all plants were injured, but some plants clearly had survived.

The final experiment was nearly identical to earlier experiments with 1- to 2-leaf seedlings, except that the blasting unit was placed 600 mm from the seedlings and each repetition of the experiment contained three replicated pots instead of four. One and two blasts of grit reduced seedling fresh weights by the same amount (84% and 83%). The weight reduction percentages for the 600 mm distance were slightly lower than corresponding values for the 300 mm distance, but probably not different in a practical sense. These results suggest that small weed seedlings die as effectively when they are abraded by grit delivered from 600 mm distance as from 300 mm distance.

Discussion

In organic crops, a single control tactic will probably not limit weed populations to acceptable levels. Often, combinations of several control methods will be needed for acceptable weed management (Bàrberi, 2002). When performed suitably, weed control from most physical tactics is adequate, but rarely excellent (e.g. Ascard, 1998; Oriade & Forcella, 1999; Melander *et al.*, 2005),

which is why Bond and Grundy (2001) and others have advocated for development of additional non-chemical weed control tactics. The air-propelled abrasive grit described in this report shreds and kills weeds upon contact and possibly may represent one additional tactic that could be engineered for use in organic production systems, in combination with other appropriate techniques. However, the current study merely represents proof-of-concept in a glasshouse and much remains unknown regarding the cost and practicality of this technology, which may be appropriate for use in organic crops, amenity areas and urban settings.

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